

# Numerical investigation into thermal load responses of railway transom bridge

Mirza, Olivia; Kaewunruen, Sakdirat; Dinh, Cong; Pervanic, Edin

DOI:

[10.1016/j.engfailanal.2015.11.054](https://doi.org/10.1016/j.engfailanal.2015.11.054)

License:

Creative Commons: Attribution-NonCommercial-NoDerivs (CC BY-NC-ND)

*Document Version*

Peer reviewed version

*Citation for published version (Harvard):*

Mirza, O, Kaewunruen, S, Dinh, C & Pervanic, E 2016, 'Numerical investigation into thermal load responses of railway transom bridge', *Engineering Failure Analysis*, vol. 60, pp. 280-295.  
<https://doi.org/10.1016/j.engfailanal.2015.11.054>

[Link to publication on Research at Birmingham portal](#)

## **Publisher Rights Statement:**

Eligibility for repository: checked 08/02/16

## **General rights**

Unless a licence is specified above, all rights (including copyright and moral rights) in this document are retained by the authors and/or the copyright holders. The express permission of the copyright holder must be obtained for any use of this material other than for purposes permitted by law.

- Users may freely distribute the URL that is used to identify this publication.
- Users may download and/or print one copy of the publication from the University of Birmingham research portal for the purpose of private study or non-commercial research.
- User may use extracts from the document in line with the concept of 'fair dealing' under the Copyright, Designs and Patents Act 1988 (?)
- Users may not further distribute the material nor use it for the purposes of commercial gain.

Where a licence is displayed above, please note the terms and conditions of the licence govern your use of this document.

When citing, please reference the published version.

## **Take down policy**

While the University of Birmingham exercises care and attention in making items available there are rare occasions when an item has been uploaded in error or has been deemed to be commercially or otherwise sensitive.

If you believe that this is the case for this document, please contact [UBIRA@lists.bham.ac.uk](mailto:UBIRA@lists.bham.ac.uk) providing details and we will remove access to the work immediately and investigate.

Accepted Manuscript

Numerical investigation into thermal load responses of railway transom bridge

Olivia Mirza, Sakdirat Kaewunruen, Cong Dinh, Edin Pervanic

PII: S1350-6307(15)30176-X  
DOI: doi: [10.1016/j.engfailanal.2015.11.054](https://doi.org/10.1016/j.engfailanal.2015.11.054)  
Reference: EFA 2779

To appear in:

Received date: 9 May 2015  
Revised date: 19 November 2015  
Accepted date: 19 November 2015

Please cite this article as: Mirza Olivia, Kaewunruen Sakdirat, Dinh Cong, Pervanic Edin, Numerical investigation into thermal load responses of railway transom bridge, (2015), doi: [10.1016/j.engfailanal.2015.11.054](https://doi.org/10.1016/j.engfailanal.2015.11.054)

This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.



## REVISION

# “Numerical investigation into thermal load responses of railway transom bridge”

(Title contains 10 words)

by

**Olivia Mirza**

School of Computing, Engineering & Mathematics  
University of Western Sydney

**Sakdirat Kaewunruen**

Birmingham Centre for Railway Research and Education  
University of Birmingham

**Cong Dinh**

School of Computing, Engineering & Mathematics  
University of Western Sydney

**Edin Pervanic**

School of Computing, Engineering & Mathematics  
University of Western Sydney

Submitted to

**Engineering Failure Analysis**

Corresponding Author:

Sakdirat Kaewunruen

Senior Lecturer in Railway and Civil Engineering  
Birmingham Centre for Railway Research and Education  
University of Birmingham  
Birmingham B15 2TT UK  
Tel: +44 (0) 1214 142 670  
E-mail: sakdirat@hotmail.com

Manuscript Summary:

Total pages	30 (including 1-page cover)
Number of figures	7
Number of tables	4

# Numerical investigation into thermal load responses of railway transom bridge

Olivia Mirza<sup>1</sup>, Sakdirat Kaewunruen<sup>2</sup>, Cong Dinh<sup>3</sup>, and Edin Pervanic<sup>4</sup>

**Abstract:** Australian railway networks suffer a large fluctuation of extreme heats each year due to their wide variety of geographical conditions. Depending on climatic, cloud and radiation conditions, an ambient temperature of 20°C could induce an equivalent thermal load absorption of track components as much as 30°C to 35°C or even more. As such, relatively high turnover of timber sleepers (crossties in a plain track), bearers (skeleton ties in a turnout), and transoms (bridge cross beams) can often be observed due to their unstable deformation and rapid deterioration. This paper investigates an application for the replacement of aging timber transoms mounted on existing railway bridges using fiber reinforced foamed urethane (FFU) transom beams, which are proven to provide environmental, safety and financial benefits. Clear benefits of the FFU material are the maintainability and constructability, especially for existing railway bridges. In this study, numerical simulations using finite element package ABAQUS have been carried out to illustrate the effect of thermal loads on the structural behavior of a railway transom bridge. The model was developed using a case study of an actual railway bridge in Kiama, Australia and it has been validated by field data measurements. It is found that nonlinear structural behavior of the bridge components exists at highly elevated temperatures. The better insight into the thermal load responses will lead to safer and more reliable rail stress adjustment practice, preventing rail misalignment or buckling.

**Keywords:** railway infrastructure, tracks, bridge, thermal load, finite element analysis, failure analysis.

---

<sup>1</sup> Senior Lecturer, School of Computing, Engineering & Mathematics, University of Western Sydney, Kingswood, NSW Australia. E-mail: o.mirza@uws.edu.au

<sup>2</sup> Corresponding Author. Senior Lecturer in Railway and Civil Engineering, School of Civil Engineering, University of Birmingham, B15 2TT, UK. E-mail: sakdirat@hotmail.com; s.kaewunruen@bham.ac.uk

<sup>3</sup> School of Computing, Engineering & Mathematics, University of Western Sydney, Kingswood, NSW Australia. E-mail: Cong.Dinh@manly.nsw.gov.au

<sup>4</sup> School of Computing, Engineering & Mathematics, University of Western Sydney, Kingswood, NSW Australia. E-mail: 16545117@student.uws.edu.au

## 1. Introduction

Critical structural components of railway track and structural systems are designed to interact in order to transfer the imposed dynamic loads from the wheels of the railway vehicle to the foundation or support structure of the rail track [1-4]. These dynamic loads include both vertical loads influenced by the unsprung mass of the vehicles and lateral loads mobilized by centrifugal action of cornering or the momentum of breaking vehicles [5]. In general, three dominant forms of railway bridge structures are transom bridges, ballast-top bridges, and concrete viaducts. Based on the current design approach, the design life span of structural bridge systems is around 100 years, [6]. Figure 1 shows a typical railway transom bridge with existing physical constraints. The rail track is built on timber cross beams, so-called 'transoms', which are supported by long-span steel girders between bridge piers.

In recent years, New South Wales (NSW) Australia has experienced unpredictable temperatures and weather conditions. Kiama, being in the south coast of NSW, also experience these unpredictable conditions. The Bureau of Meteorology Australia has recorded its coolest summer in 2011-2012. Last record of similar temperatures was back in the summer of 1996-1997. The max mean temperature for Kiama during December for that period was 23.6 degrees making it one of the coldest summers on record. Strong cold southern winds of up to 85 km/h were also recorded [7]. This observation was drawn from the Bombo Headland observation station. However, there is no cloud observation due to the nearest one being 34km away in Wollongong. These unpredictable weather conditions make it very difficult to practically design structural parameters relating to any bridge in the local area in the first place. As such, the initial design generally adopted the average environmental data from reliable sources available at the time, and then rail creep monitoring at the bridge ends forms an essential part of rail maintenance and operation management. In this study, a railway transom bridge over the Minnamurra River, in Kiama NSW, is investigated. The railway bridge links Sydney to the South Coast and spans over 100m of waterway. As mentioned, there is no adequate data taken for the bridge under higher temperatures

conditions. The renewal of the bridge was conducted in 2012 by replacing timber transoms with fibre-reinforced foamed urethane (FFU) transoms.

The thermal response of the bridge is crucial when analysing the impact it has on certain component and the whole structure. In the case of thermal expansion occurring, the ballast, sleeper, the steel rail and the rail pads could make the bridge inadequate to support moving trains. As a result, it is important to understand the effect of elevated temperature and thermal expansion on the bridge. 3D finite element analyses using ABAQUS have been conducted to simulate the effect on the railway line due to higher temperatures that are normally experienced during that time of the year. This is focussed specifically in the regards to the thermal behaviour of the rails and the supports. The finite element analyses can predict the failure mode and failure zone of the bridge when exposed to elevated temperatures. The outcome of this study will allowed the practice engineers to redesign and strengthened the bridge for future railway bridge construction.

## **2. Minnamurra Railway Bridge and its Support Structures**

Bridge transoms or sleepers are the members oriented perpendicular to the rails and distribute the rail vehicle loads imposed through the rail to the superstructure below. Transoms also provide lateral separation of the rails and stability of gauge width between the rails. Currently the most common materials used for intermediate transoms on railway bridges are hardwood timbers. Feasible alternatives for the replacement of deteriorated hardwood timber transoms have been developed recently in Australia [8-10]. According to Manalo et al. [11], existing materials used for railway transoms are timber, concrete and steel with each having their own strengths and weaknesses.

Concrete and steel are not considered to be a viable alternative to timber transoms. Due to high-frequency dynamic forces, high stiffness characteristics and reduced capacity to flex under load (poor tensile strength), traditional concrete transoms typically require a much deeper section than timber transoms. This depth makes traditional concrete transoms relatively expensive and quite heavy, with a typical weight of 285kg. It was also found that concrete structures tend to be the most

cost-effective solution for the railway sleeper application in plain tracks. Benefit cost ratio of concrete sleepers was superior to composites [12-13]. In contrast, concrete transoms for railway bridge application fail to enter the rail market due to excessive weight and thickness. In many practical cases, such conversion is not always possible due to aging bridge structural systems and associated foundation [14-15].

Recent developments of new materials and composites create opportunities to adopt such new alternative materials in practice. As part of a field trial, '*fibre reinforced foamed urethane*' (FFU) transoms have recently been installed on a railway bridge in Kiama crossing over the Minnamurra River, NSW Australia. Field reports however suggested that there were some technical issues associated with existing structural steel girders prior to the installation. Figure 2 shows the clogged gap between main steel girders, which cannot be freely extensible on the roller support. This implies that the FFU transom replacement has been conducted on imperfect existing structure, which may or may not impair structural performance of the FFU material. Note that the initial design allows the gap around 40mm at a design average temperature (20°C). Tables 1 and 2 provide bridge details related to dimensions and steel material properties. Table 3 shows the properties of FFU transoms. The current bridge transoms are spaced at about 450mm centres and they do not provide a continuous and impervious platform across the stringers and girders of the bridge, as shown in Figure 3.

### **3. Finite Element Simulation**

#### **3.1 Materials**

A three dimensional finite element of model of the steel bridge and track support systems has been developed using a finite element package ABAQUS. The model has been validated using previous work by Mirza et al. [16, 17] and using field measurement data by Kaewunruen [18]. In this model, concrete has been modeled using elasto-plastic elements in ABAQUS. Plain concrete with the design compressive strength ( $f'_c$ ) of 50 MPa has been adopted for use in the

finite element analysis of the panels. The non-linear behaviour of the plain concrete under ambient conditions is represented in Figure 4a, which shows three distinct portions of the stress strain curve. There are two parts to the curve within the compressive section, which makes up the non-linear behaviour of the concrete. ABAQUS requires the young's modulus of concrete ( $E_c$ ) and poisons ratio ( $\nu$ ) to calculate the first part of the stress strain curve, which is assumed to be linear elastic and acts up to a proportional limit stress of  $0.4(f'_c)$  [16, 17].

Young's modulus of concrete ( $E_c$ ) has been calculated to be 34652 MPa from Equation (1) adopted from AS3600 [19] and poisons ratio ( $\nu$ ) of 0.2 has been adopted.

$$(\rho^{1.5}) \times (0.024\sqrt{f_{cmi}} + 0.12) \text{ When } f_{cmi} > 40 \text{ MPa} \quad (1)$$

For the second section of the stress strain curve in the compressive region, the stress can be found as a function of strain following Equation (2) as suggested by Mirza et al. [16]:

$$\sigma_c = \frac{f'_c \gamma \left( \frac{\epsilon_c}{\epsilon'_c} \right)}{\gamma - 1 + \left( \frac{\epsilon_c}{\epsilon'_c} \right)^\gamma} \quad (2)$$

Where:

$$\gamma = \left| \frac{f'_c}{32.4} \right|^3 + 1.55 \quad \text{and } \epsilon'_c = 0.002$$

In the tension zone the stresses are assumed to increase linearly until the concrete cracks after which the stresses decrease linearly to zero.

The stress strain relationship of steel materials and reinforcing steel can be modelled using a tri-linear curve as shown in Figure 4b [17]. These sections are initially linear elastic followed by strain softening and finally yielding. Common material properties for steel elements are Young's modulus ( $E_s$ ) = 200000 MPa and Poison's ratio ( $\nu$ ) = 0.3. Furthermore, the stress strain relationship of the steel is assumed to be similar in both tension and compression. The initial material properties used for modelling the FFU elements within ABAQUS are presented in Table 3 and the linear elastic property has been adopted.



### 3.2 Modelling

Three-dimensional eight node solid elements incorporating linear approximation of displacements, reduced integration and hourglass control (C3D8R) have been used in this study for ballast, connectors and box girder. The C3D8R element type has been found to be sufficient for linear and nonlinear models and are capable of incorporating contact properties, handling large deformations and accommodating plasticity. The use of C3D8R elements increases the rate of convergence of the solutions [20-22]. For timber transoms, FFU transoms and steel rail, three-dimensional twenty node solid elements were adopted. The increase of nodes for the elements were desirable to accurately determine load slip between transoms and steel rail. It is assumed that the rails transfer longitudinal creep force directly on the transoms to reflect the worst case scenario that the rail can sometimes be installed directly onto the transoms. As a result, the baseplate model was excluded for the longitudinal load analysis.

Validation and sensitivity analyses of mesh size were conducted in comparison with previous established model by Mirza et al. [17] and with field measurements by Kaewunruen [18, 23]. Figure 5 shows a three-dimensional finite element model of the bridge system and track support structure. The comparison between mid-span deflections of bridge-supported rail under a passenger train load is in good agreement with field data (about 2 mm).

### 3.3 Contact, interface and boundary conditions

When defining either interactions or constraints it is necessary to designate a master surface and a slave surface. The surface of the element with the stiffer material (steel, concrete) is defined as the master surface and the slave surface is assigned to the less stiff element (FFU, ballast). ABAQUS then places a “kinematic constraint” to ensure that a slave surface cannot penetrate a master surface.

Figure 6 illustrates the boundary/restraints conditions outline areas that restricted in terms of movement and rotations and according to the existing supports on the bridge. This simulates the

actual support condition (as per design) with calculations by using symmetrical boundary conditions making it less intensive and less complicated [20-21]. A properly set boundary/restrain has been properly set to accurately imitate the actual bridge conditions as shown in Figure 7 (as per RailCorp, [24-25]). Bear in mind that the concrete transoms are fixed to the ballast whilst the FFU transoms are not constrained.

### 3.4 Thermal load application

In real life, railway track buckles under compression induced by elevated temperature over stress-free temperature of rails. In this study, a simplification of load stress has been adopted in order to evaluate the weakness location of the track-bridge system. In general, such location is at the bridge approach and this is where rail creeps are monitored commonly in industry best practice. As a result, the finite element model and load application have been simplified and correlate to the field monitoring of longitudinal rail creepage at the bridge end. Thermal load is defined as the temperature that causes the effect on the railways structures such as ballast, steel rails, steel box girders and transoms, such as outdoor air temperature, solar radiation and underground temperature. The change of the temperature cause these members to have thermal stress and is defined as the effect of thermal load. This is initial study on the thermal loading of this bridge, therefore Equation 3 expressed the thermal load that applied to the bridge.

$$f = \alpha \Delta T E \quad (3)$$

where,

$f$  = Thermal Load

$\alpha$  = Coefficient of thermal expansion

$\Delta T$  = Change in temperature

$E$  = Young's modulus.

The thermal loads nominated above were applied to each model using the modified RIKS method available within ABAQUS as shown in Figure 8. The RIKS method allows a proportion of the total load to be incrementally applied to the model with the equilibrium iteration check completed for each increment prior to the next proportional load application. Uniformly distributed load (axially) is considered in this study. Due to the main objective of this investigation being to analyse the effect of thermal loading on a railway bridge, uniformly distributed load will be better suited. This is due to the abundance thermal expansion exposure of the bridge, therefore, concentrated loads are not considered. The uniformly distributed loads have also been chosen due to the entire external surface of the railway bridge being penetrated by thermal radiation. The critical review [26-33] has showed that this study provides new and critical insight into the risk of failure of railway track-bridge systems due to thermal conditions. This insight will help track engineers to better manage the risk and to maintain the railway track more effectively. It is important to note that railway track has lesser resistance to thermal load compared to those of the bridge. Also, most previous research studies have focused on the bridge structure itself [34-36]. This has paved the pathway to impact of this study, which is reasonably new and significant to railway engineering practice.

#### **4. Results and discussion**

There are seven temperatures were analysed for this study. The temperatures ranged from 30°C to 60°C with 5°C interval. Figure 9 shows the stress distribution at 30°C and 35°C. Figures 9a and 9c demonstrate that the highest stress occurs on the face of the steel box girder, and then transferred onto the long chords of the bridge. From the FEM, it was observed that the stress is also distributed further down the bridge but decreases in intensity. Figures 9b and 9d illustrate the location in which the steel rails resist displacements, which cause a build-up of stress in the rail. Build-up stress causes reaction forces to return displacement against current direction. These locations consist of 5 points at the unrestrained at the front and 5 points at the fully restrained transom at the back.

The displacement of the FFU transom at the front is measured at -0.84 and -1.9 mm whilst and -0.70 and -1.7 mm at the back shown in Figures 10a and 10b for thermal load of 30°C and 35°C, respectively. The decreased in displacement at the back could be caused by the displacement of the steel rails which is moving in the opposite direction to the transom and the concrete transom is fixed to the ballast. The displacement of the rail at the front is measured at 0.39 and 0.48 mm whilst 0.20 and 0.19 mm at the back which is shown Figures 10a and 10b for thermal load of 30°C and 35°C, respectively. The reduced displacement at the back could be caused by reaction forces resisting the movement of the steel causing it to elongate at different lengths and the reaction forces resisting the movement of the steel causing return back to original position. When compared the steel rail movement with different thermal loading, it was observed that at 30°C, the steel rail is moving in the opposite direction to the transoms. When the thermal loading increased to 35°C, at 50 kN it was observed that the steel rail at the back and front moves in the same direction with transom but insignificant.

Figure 11 shows the stress distribution at 40°C and 45°C. The stress distributions show similar trend to previous thermal loading with higher stress concentrations. However, the stress is still within the yielding stage. The displacement of the FFU transom at the front is measured at -4.2 and -8.3 mm whilst and -4.0 and -8.0 mm at the back shown in Figures 12a and 12b for thermal load of 40°C and 45°C, respectively. They show similar trend to the previous temperatures.

The displacement of the rail at the front is measured at 0.48 and 0.34 mm whilst 0.19 and -0.02 mm at the back which is shown Figures 12a and 12b for thermal load of 40°C and 45°C, respectively. Even though the rail shows similar trend to previous thermal loading, for 40°C, the steel rails moved in the same direction as FFU transoms at 80 kN whilst for 45°C, the steel rails moved in the same direction when the thermal loading is at 100 kN. This explained the unrestrained and restrained boundary condition for transoms and the reaction force of transoms

are higher than the steel rails. Figure 12 also illustrate the beginning of steel rail buckle or misalign at the initial stage. The displacement is 0.25 mm, which is negligible at the stage.

Figure 13 shows the stress distribution at 50°C, 55°C and 60°C. The stress distributions show similar trend to previous thermal loading with higher stress concentrations. However, at 55°C onward the stress is exceeding the yielding stage. The analysis shows the thermal load instability at 55°C. At this stage, the thermal load effect may cause rail track to buckle. Build-up stress causes reaction forces to return displacement against current direction. The rails could have elongated due to temperature which would in turn displace the transoms a larger distance or rail misalignment (buckling).

The displacement of the FFU transom at the front is measured at -17.9, 29.9 and -44.5 mm whilst and -17.2, 28.6 and -36.9 mm at the back shown in Figures 13a, 13b and 13c for thermal load of 50°C, 55°C and 60°C, respectively. The displacement at the front and back are quite similar, the difference could be caused because the transoms at the back are connected to the rails which would allow them to displace more than the first set of transoms. The displacement of the rail at the front is measured at -0.8, -0.9 and -1.01 mm whilst -0.21, -0.23 and -0.27 mm at the back which is shown Figures 13a, 13b and 13c for thermal load of 50°C, 55°C and 60°C, respectively. This proved that at certain magnitudes of force, the displacement of the rails is acting with the force. When the reaction forces are greater the displacement is acting against the force as shown in Figure 14c. The displacement is moving in one direction and then is returning back to its origin, this is caused by the reaction forces that are preventing the rails support from displacing and are pushing back.

## **5. Concluding Remarks**

Global demand of timber-replacement alternatives for railway construction and maintenance is significant, especially in some specific fit-for-purpose projects such as brown-field railway transom bridges. This paper presents an application of fibre reinforced foamed

urethane (FFU) material, which provide resiliency for either a spot replacement or a total renewal of aging timber components within the railway transom bridge. To assure the design criteria under aggressive environmental effects, this paper has established a 3D finite element model of bridge and track systems. Evidenced by many problems in railway systems such as track buckling, train speed restriction due to heat, and so on, the study into the environmental resilience of rail infrastructure is inadequate. This study is thus important in the field of engineering failure analysis where the risk of extreme weather can be realised and can significantly affect the public safety and reliability of railway systems. The goal of this paper is to demonstrate the effect of extreme weather on track-bridge systems. The insight into the track-bridge behaviour will enable better planning and more efficient and effective maintenance regime.

The finite element modelling, carried out for the Minnamurra bridge case study, has been used to investigate the behaviour of bridge structure, which consists of the FFU transoms, steel box girder, steel rails and supports when exposed to thermal loading. However this paper only presents the effect on transoms and steel rails under different support condition. This thermal load effects are measured in terms of longitudinal displacement (along the track length) of the individual components.

The research concluded that:

1. FFU transoms on the bridge displaced along the track more compared to concrete transoms installed on adjacent open tracks due to no restrained from box girder and its fixture. However the displacement discrepancy is minimal.
2. Allowing for additional restraints to tie the transoms to the box girder would reduce the magnitude of both longitudinal and transverse displacements of the transoms.
3. The creepage or longitudinal displacement of the rails can be minimal by degree of fixture or restraint into transoms.

4. This research firstly presents the longitudinal deformation of transom and rails systems. The insight will assure appropriate maintenance by longitudinal rail stress adjustment at or near railway bridge approaches in order to prevent track misalignment or buckling. The insight into the structural behaviour under thermal loads will help rail engineers better manage the risk of failure of track-bridge systems, which could lead to train derailments and catastrophic losses.

## 6. Further Studies

This research however does not take into consideration the interaction between transoms and box girder and ballast, the effect of train load under thermal loading and derailment. Further research is necessary to study these interactions and loading condition. Phase 2 and 3 of this research will focus on these aspects.

## Acknowledgement

The authors are grateful to the Institute of Infrastructure Engineering, University of Western Sydney Australia for the financial support throughout this study. The second author wishes to thank Japan Society for the Promotion of Science (JSPS) for his JSPS Invitation Fellowship for Research (Long-term) at Railway Technical Research Institute, Tokyo Japan.

## References

- [1] Indraratna, B., Salim, W., and Rujikiatkamjorn, R. 2011. *Advanced Rail Geotechnology - Ballasted Track*, CRC Press, The Netherlands.
- [2] Remennikov, A.M., and Kaewunruen, S. 2008. A review of loading conditions for railway track structures due to train and track vertical interaction, *Structural Control and Health Monitoring*. **15**(2), 207-234.
- [3] Remennikov, A.M., and Kaewunruen, S., 2014. Experimental load rating of aged railway concrete sleepers, *Engineering Structures*, In press.
- [4] Remennikov, A.M., Murray, M.H., and Kaewunruen, S., 2012, "Reliability based conversion of a structural design code for prestressed concrete sleepers," *Proceedings of the Institution*

of *Mechanical Engineers: Part F Journal of Rail and Rapid Transit*, 226(2), 2012, pp. 155-173.

- [5] Bonnett, CF 2005, *Practical railway engineering*, Imperial College Press, Hackensack.
- [6] Standards Australia, AS5100.2 2004, 'Bridge design - Part 2: Design loads', *Australian Standards*, Sydney Australia
- [7] Bureau of Meteorology, 2014. State of the Climate 2014 Report, Access Online [URL <http://www.bom.gov.au/state-of-the-climate/>]
- [8] Kaewunruen, S. 2014, "Monitoring structural deterioration of railway turnout systems via dynamic wheel/rail interaction." *Case Studies in Non-destructive Testing and Evaluation*, 1(1): 19-24.
- [9] Kaewunruen, S. 2014, "Monitoring in-service performance of fibre-reinforced foamed urethane material as timber-replacement sleepers/bearers in railway urban turnout systems." *Structural Monitoring & Maintenance*, 1(1): 131-157 (invited).
- [10] Kaewunruen, S. and Remennikov, A.M., 2008, "Effect of a large asymmetrical wheel burden on flexural response and failure of railway concrete sleepers in track systems", *Engineering Failure Analysis*, 15(8): 1065-1075.
- [11] Manalo, A, Aravinthan, T, Karunasena, W and Ticoalu, A. 2010. 'A review of alternative materials for replacing existing timber sleepers', *Composite Structures*, vol. 92, no. 3, pp. 603-11.
- [12] Remennikov, A., and Kaewunruen, S. 2007. "Experimental determination of energy absorption capacity for railway prestressed concrete sleepers under impact loading." *International Conference on Structural Engineering and Construction - ISEC2007*, Sep 26-28, Melbourne, Australia, [CD Rom].
- [13] Kaewunruen S, Remennikov AM and Murray MH (2014) Introducing a new limit states design concept to railway concrete sleepers: an Australian experience. *Front. Mater.* 1:8. doi: 10.3389/fmats.2014.00008
- [14] Griffin, D.W.P., Mirza, O., Kwok, K., and Kaewunruen, S. 2014. "Composite slaps for railway construction and maintenance: A mechanistic review", *The IES Journal Part A Civil and Structural Engineering*, 7(4): 243-262.



- [15] Griffin, D. W. P., Mirza, O., Kwok, K. & Kaewunruen, S. 2015, "Finite element modelling of modular precast composites for railway track support structure: A battle to save Sydney Harbour Bridge", *Australian Journal of Structural Engineering*, 16(2): 150-168, <http://dx.doi.org/10.7158/S14-025.2015.16.2>
- [16] Mirza, O, Uy, B., and Patel, N. 2010. 'Behaviour and strength of shear connectors utilising blind bolting', paper presented to 4th International Conference on Steel and Composite Structures, Sydney, Australia.
- [17] Mirza, O., Zhu, X. and Uy, B. 2011. 'Condition Assessment and Strengthening of Shear Connection Systems for Composite Bridges', *Sustainable Bridges*.
- [18] Kaewunruen, S. 2013. "Review of Bridge End Improvement Programs – Minamurra Project" Technical Report No. TR224, Track Services RailCorp, Australia, December, 27p.
- [19] Standards Australia, AS3600 2001, 'Structural Concrete design', *Australian Standards*, Sydney Australia
- [20] Mirza, O. and Uy, B. 2011. 'Behaviour of composite beam-column flush end-plate connections subjected to low-probability, high-consequence loading', *Engineering Structures*, vol 33, no 2 , pp 647 - 662
- [21] Mirza, O. and Uy, B. 2009. 'Behaviour of headed stud shear connectors for composite steel-concrete beams at elevated temperatures', *Journal of Constructional Steel Research*, vol 65, no 3 , pp 662 - 674
- [22] Lam, D., and El-Lobody, E. 2001. 'Finite Element Modelling of Headed Stud Shear Connectors in Steel-Concrete Composite Beam', in A Zingoni (ed.), *Structural Engineering, Mechanics and Computation*, Elsevier Science, Oxford, pp. 401-408.
- [23] Kaewunruen, S., and Remennikov, A.M. 2009. 'Progressive failure of prestressed concrete sleepers under multiple high-intensity impact loads', *Engineering Structures*, vol. 31, no. 10, pp. 2460-73.
- [24] RailCorp 2010, *ESC 310 RailCorp Engineering Standard - Underbridges*. Sydney, Australia.
- [25] RailCorp 2013, *ESC 220 RailCorp Engineering Standard - Track Rail and Rail Joints*, Sydney, Australia.[URL [http://engineering.railcorp.nsw.gov.au/Disciplines/Civil/ESC\\_220.pdf](http://engineering.railcorp.nsw.gov.au/Disciplines/Civil/ESC_220.pdf)].

- [26] Bornet, L., Andersson, A., Zwolski, J., Battini, J.M., 2015. 'Influence of the ballasted track on the dynamic properties of a truss railway bridge', *Structure and Infrastructure Engineering*, 11(6): 796-803.
- [27] Ding, Y.L., Wang, G.X., Sun, P., Wu, L.Y., Yue, Q., 2015. 'Long-term structural health monitoring system of a high-speed railway bridge structure', *The Scientific World Journal*, ID 250562. <http://dx.doi.org/10.1155/2015/250562>
- [28] Vican, J., Gocal, J., Odrobinak, J., Moravcik, M., Kotes, P. 2015. 'Determination of railway bridges loading capacity', *Procedia Engineering*, 111, 839-844.
- [29] Braun, J., Stroner, M., 2014, 'Geodetic measurement of longitudinal displacements of the railway bridge', *Geoinformatics FCE CTU 12*, 2014. <http://dx.doi.org/10.14311/gi.12.3>
- [30] Srinivas, V., Ramanjaneyulu, K., Saravana Kumar, K., Parivallal, S., Kesavan K., Ravisankar, K., Lakshmanan, N., Lyer, N.R. 2011. 'Evaluation of longitudinal force on a railway rbridge based on strain measurement', *Experimental Techniques*, 37(1): 55-67. DOI: 10.1111/j.1747-1567.2011.00747.x
- [31] Yan, B., Dai, G.L., 2012. 'CWR longitudinal force of cable-stayed bridge of high-speed railway', *Journal of the China Railway Society*, Tsinghua Tongfang Knowledge Network Technology Co., Ltd.(Beijing).
- [32] Ren, J., Liu, X., Lin, H., and Shubber, A. 2009. 'Influencing factors of temperature force and displacement of longitudinal continuous ballastless seamless turnout on bridges for PDLs'. *International Conference on Transportation Engineering 2009*: pp. 207-212.
- [33] Ruge P, Widarda DR, Schmälzlin G, Bagayoko L. 2009. 'Longitudinal track-bridge interaction due to sudden change of coupling interface', *Computers & Structures*, 87(1-2): 47-58.
- [34] Dai, G.L., Yan, B., 2012., 'Longitudinal forces of continuously welded track on high-speed railway cable-stayed bridge considering impact of adjacent bridges', *Journal of Central South University*, 19(8): 2348-2353.
- [35] Yan, B., Dai, G.L., Guo, W.H., 2015, 'Longitudinal force in continuously welded rail on long-span tied arch continuous bridge carrying multiple tracks', 22(5): 2001-2006.

- [36] Ryjáček P., Vokáč M., 2014, 'Long-term monitoring of steel railway bridge interaction with continuous welded rail', Journal of Constructional Steel Research, 99: 176-186.

**Table 1** Dimensions of Minnamurra bridge and its components

<b>Length</b>	127.95m
<b>Height</b>	2m from base of box girder to top of the rail
<b>Sleeper Width</b>	2800mm
<b>FFU Transoms</b>	250mm x 190mm (this is standard sleepers installed on the bridge)
<b>Normal Concrete Sleepers</b>	225mm x 180mm (adjacent tracks – this is standard sleepers for open plain track)
<b>Special Concrete Sleepers</b>	260mm x 240mm (adjacent tracks – this is special sleepers used at the bridge approaches)

**Table 2** Material types

Steel plate	Grade 350 complied to AS/NZ 3678
Structural Steel Work	Comply with AS 4100
Square Hollow Section	Grade C350L0 to AS 1163
Mesh Panels	25x25x3.15 Welded Wire Mesh Comply to AS 2423

**Table 3** Basic properties of FFU material in comparison with timber bearers (Kaewunruen 2014a)

Properties	Australian hardwood bearers <sup>1</sup>	Birch bearers <sup>2</sup>	FFU bearers			
			New	After 10 years	After 15 years	After 30 years
Service life (years)	5-10	5-10	50	40	35	20
Density (kg/m <sup>3</sup> )	1050 - 1120	750	740	740	740	740
Bending strength (MPa) > 70	65	80	142	125	131	116
Vertical compression strength (MPa) > 40	60	40	58	66	63	55
Shear strength (MPa) > 7	6.1	12	10	9.5	9.6	7
Elastic modulus (MPa) > 6000	16,000	7100	8100	8044	8788	8414
Fatigue flexural strength	50,000 cycles at 40 MPa	50,000 cycles at 40 MPa	1 million cycles at 94 MPa			
Hardness (MPa)	10	17	28	25	17	
Water absorption (mg/cm <sup>2</sup> ) < 10	137	137	3.3	3.3	3.3	3.3
Impact bending strength (MPa) @ 20 C @ -20 C	- -	20 8	41 41	- -	- -	- -
Destructive voltage (kV) - dry (>20,000) - wet (>20,000)	8 <1	8 <1	>25 22	>25 24	>25 23	>25 25
Insulation resistance (Ω) - dry (> 1.0x10 <sup>4</sup> ) - wet (> 1.0x10 <sup>4</sup> )	6.6x10 <sup>7</sup> 5.9x10 <sup>4</sup>	6.6x10 <sup>7</sup> 5.9x10 <sup>4</sup>	1.6x10 <sup>13</sup> 1.4x10 <sup>8</sup>	2.1x10 <sup>12</sup> 5.9x10 <sup>10</sup>	3.6x10 <sup>12</sup> 1.9x10 <sup>9</sup>	8.2x10 <sup>11</sup> -
Dog spike pull-out strength (kN) > 15	25	25	28	28	23	22
Screw spike pull-out strength (kN) > 30	40	43	65	39	44	33

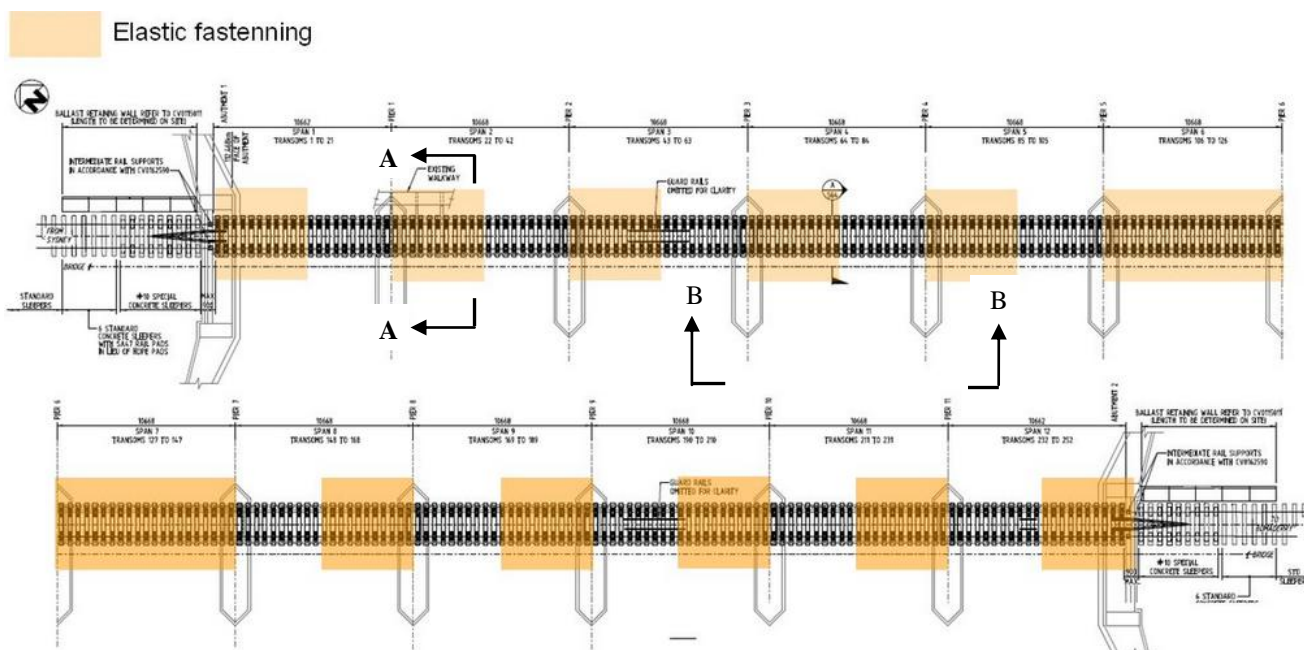
<sup>1</sup>Timber bearer properties are derived from AS1720 Strength Group 2<sup>2</sup>Birch timber bearer properties are derived from the technical datasheet



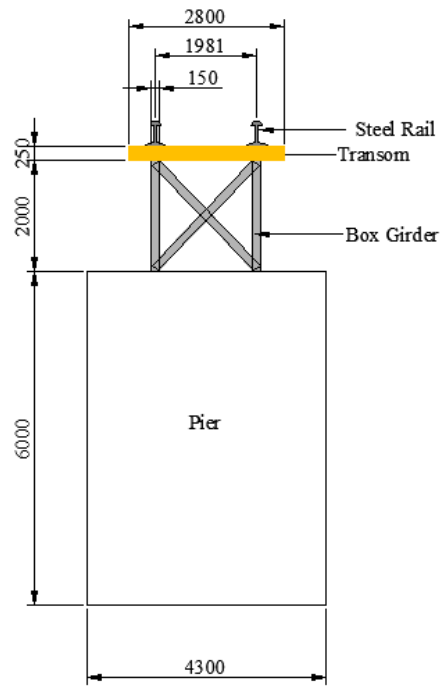
**Figure 1** Aging railway transom bridge



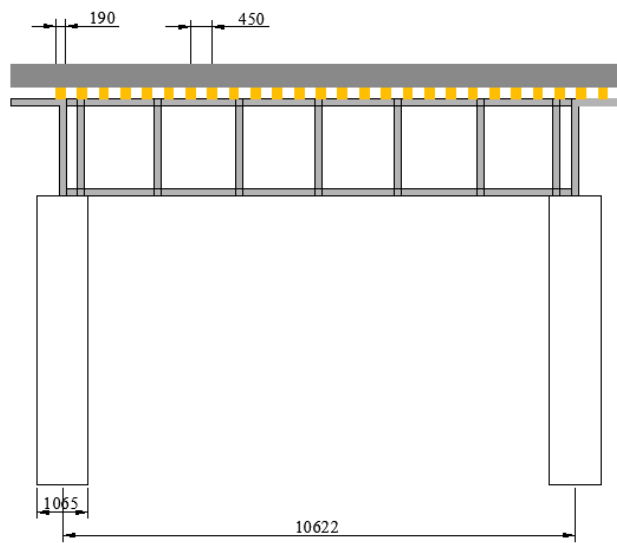
**Figure 2** Bridge girder gap at Minnamurra  
B



(a) Plan view and area with elastic fasteners (with longitudinal load resistance)



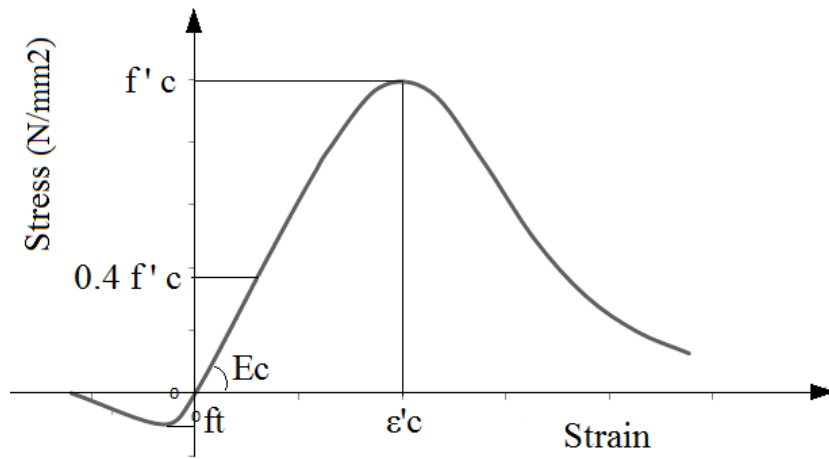
(b) Cross section view (unit in mm)



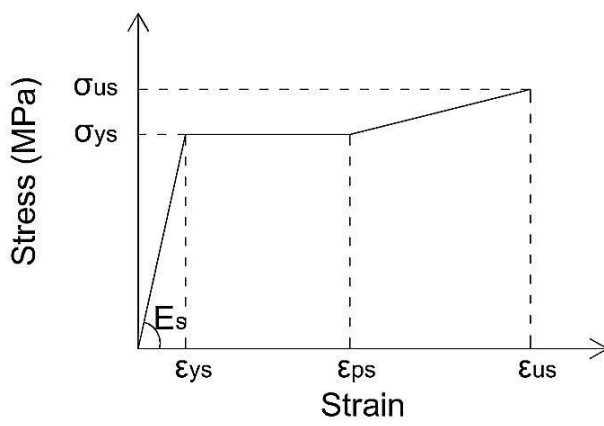
(c) Side view (unit in mm)

**Figure 3** Structural bridge system at Minnamurra





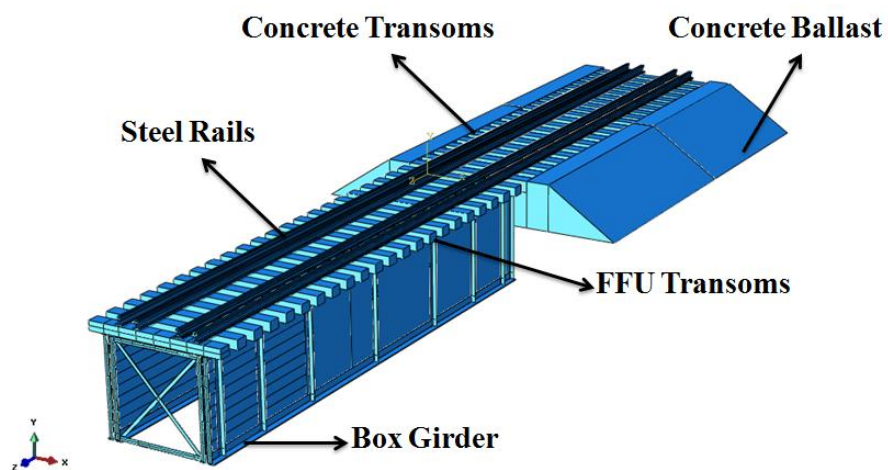
a) Stress strain curve for normal concrete



Element	$\sigma_{us}$	$\varepsilon_{ps}$	$\varepsilon_{us}$
Steel beam	$1.28\sigma_{ys}$	$10\varepsilon_{ys}$	$10\varepsilon_{ys}$
Steel Reinforcing	$1.28\sigma_{ys}$	$9\varepsilon_{ys}$	$40\varepsilon_{ys}$
Steel Rail/ Connectors/ Transom	-	$25\varepsilon_{ys}$	-
Ballast	-	$32\varepsilon_{ys}$	-

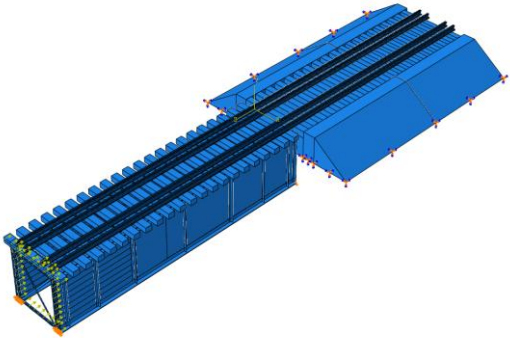
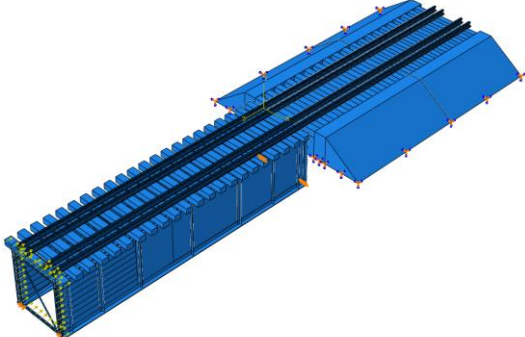
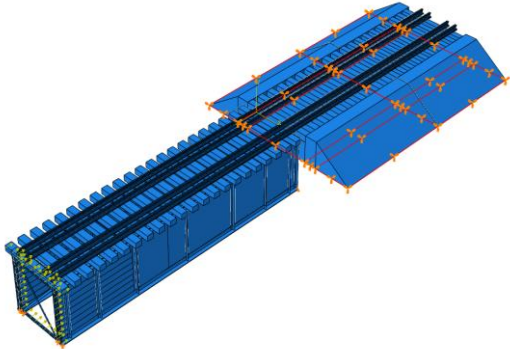
b) tri-linear stress / strain curve for different material

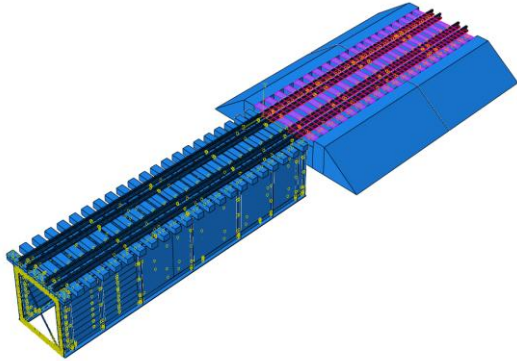
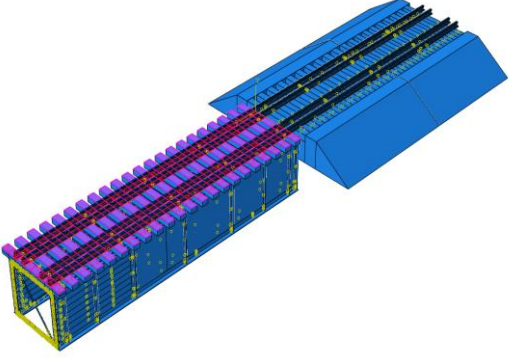
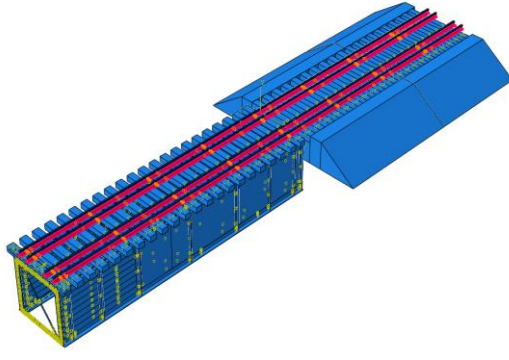
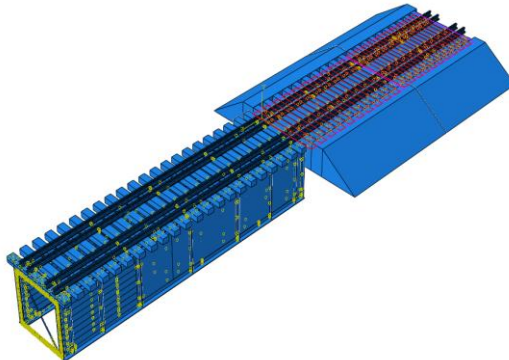
**Figure 4** Material characteristics for the 3D finite element model

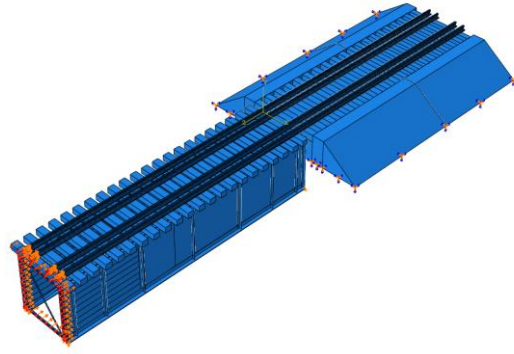


**Figure 5** 3D FE Model of Bridge-Track Systems

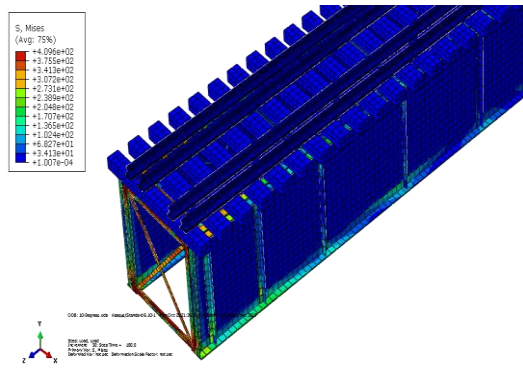


Supports Boundary Conditions	Model	Description of support locations
Pinned supports		Between Pier and steel box girder (highlighted region)
Roller Supports		Between Pier and steel box girder (highlighted region)
Fixed Supports		Between ballast and ground (highlighted region)
<b>Figure 6</b> Support Conditions for Bridge-Track Systems		

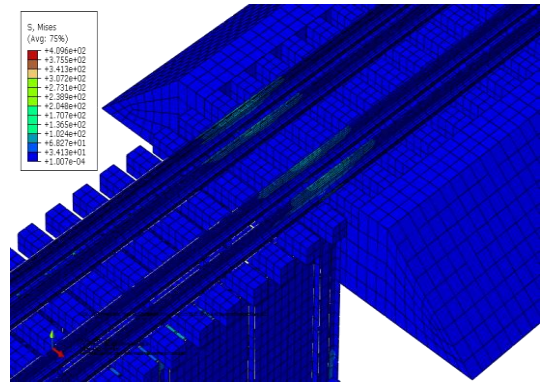
<b>Constraint Boundary condition</b>	<b>Model</b> (highlight at the boundary condition)	<b>Description</b>
<b>Surface contact</b>		<b>Concrete transom (Slave) to steel rails (Master)</b>
<b>Surface contact</b>		<b>FFU transom (Slave) to steel rails (Master)</b>
<b>Surface contact</b>		<b>Steel rails (Master) to connectors (Slave)</b>
<b>Surface contact</b>		<b>Concrete transom (Master) to ballast (Slave)</b>
<b>Figure 7 Constraints and Interaction of Bridge-Track Systems</b>		



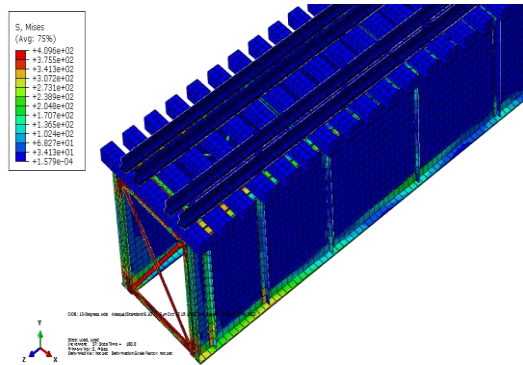
**Figure 8** Thermal Loading Condition of Bridge-Track Systems



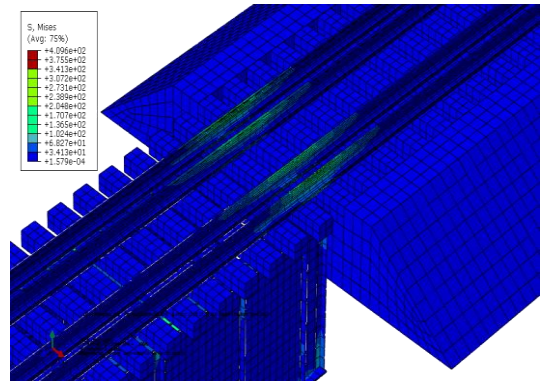
a) Stress Distribution at Front at 30°C



b) Stress Distribution at Back 30°C

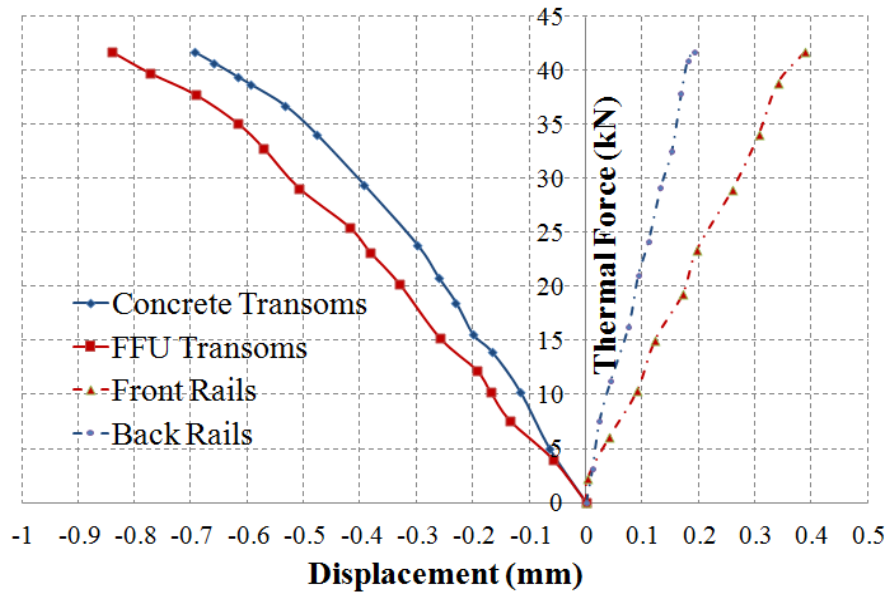


c) Stress Distribution at Front at 35°C

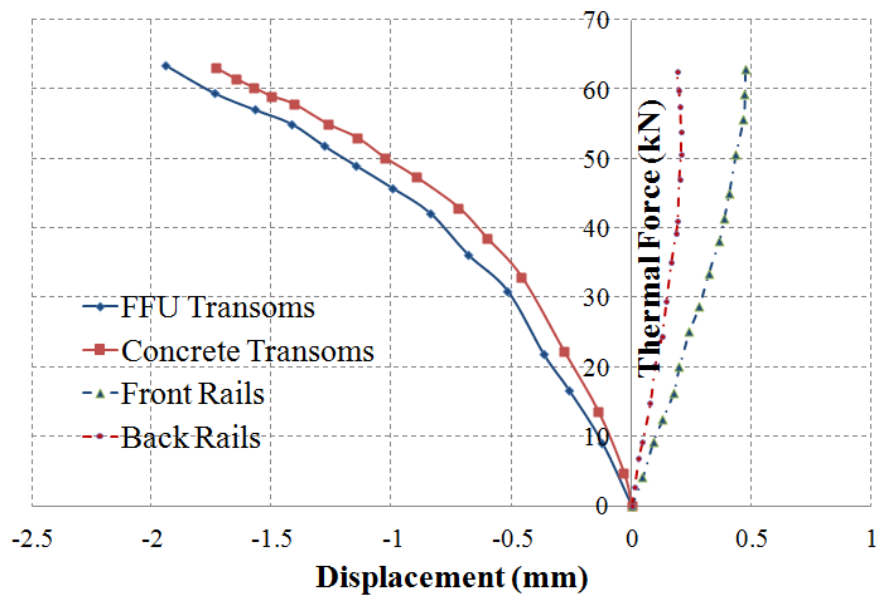


d) Stress Distribution at Back 35°C

**Figure 9** Stress Distribution at 30°C and 35°C

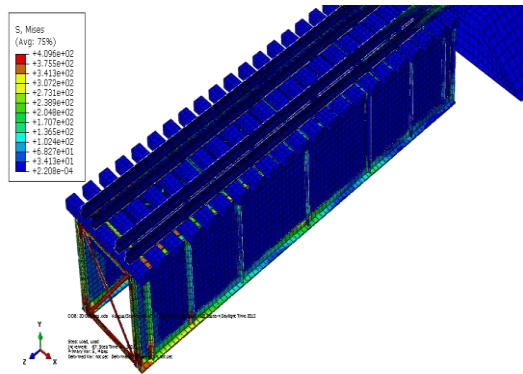


(a) Displacement of transoms and steel rail at 30°C

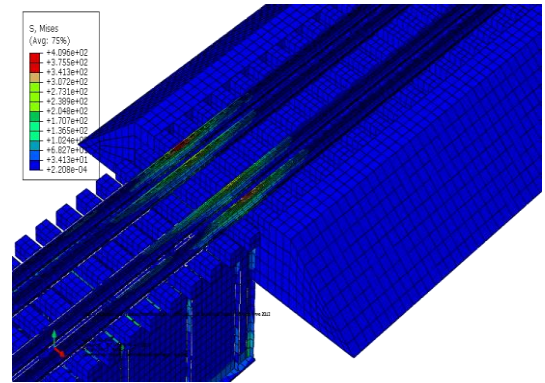


(b) Displacement of transoms and steel rail at 35°C

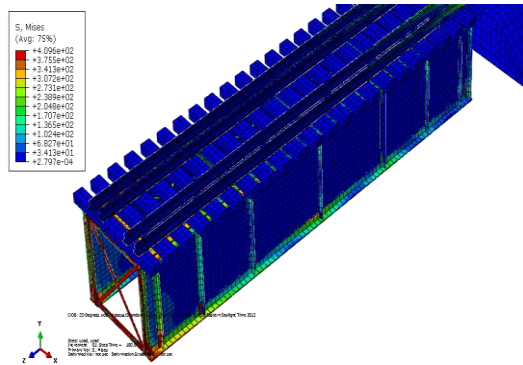
**Figure 10** Thermal loads response of Bridge-Track Systems at 30°C and 35°C



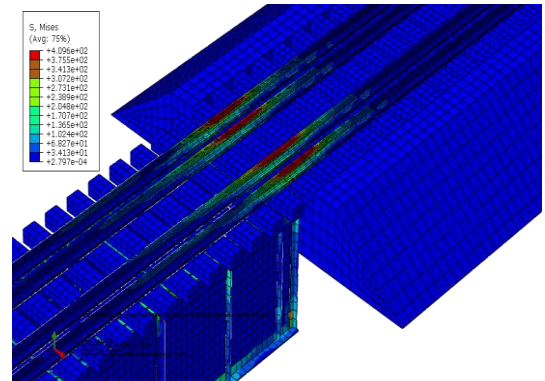
a) Stress Distribution at Front at 40°C



b) Stress Distribution at Back 40°C



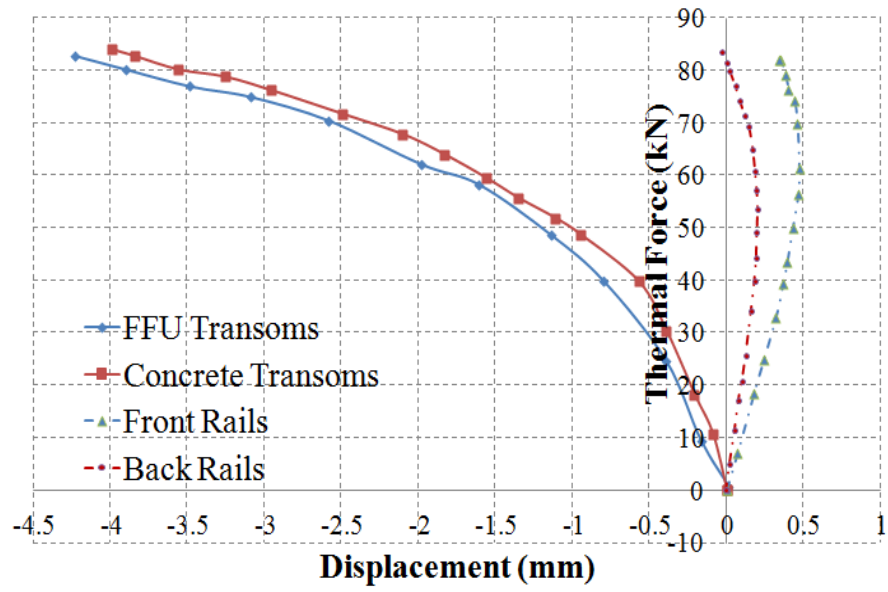
c) Stress Distribution at Front at 45°C



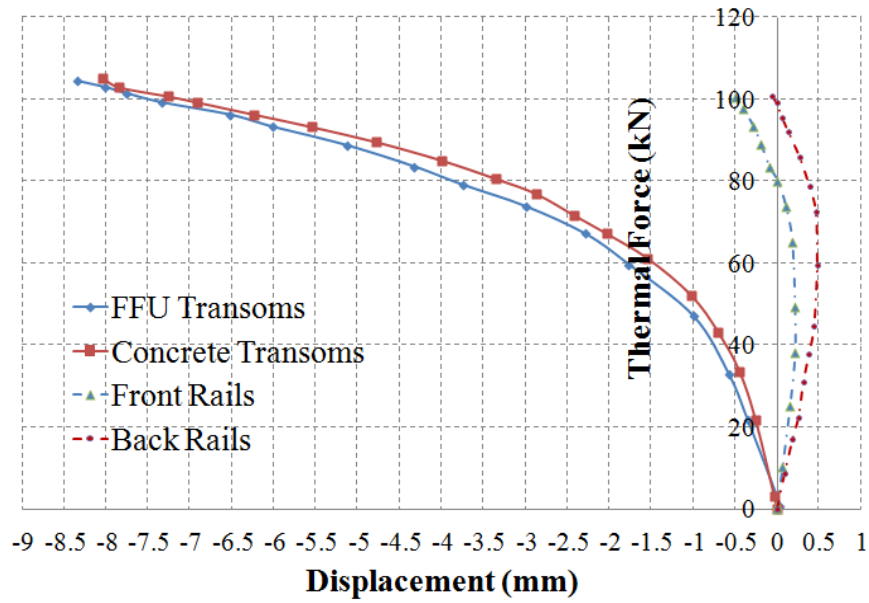
d) Stress Distribution at Back 45°C

Figure 11 Stress Distribution at 40°C and 45°C



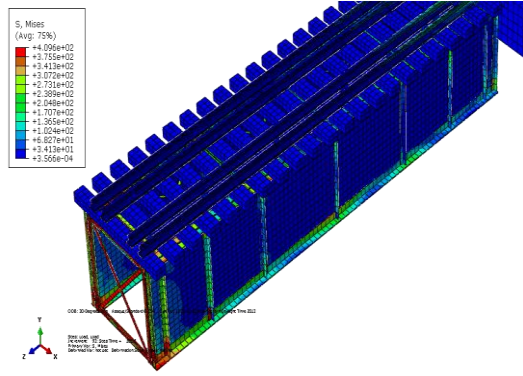


(a) Displacement of transoms and steel rail at 40°C

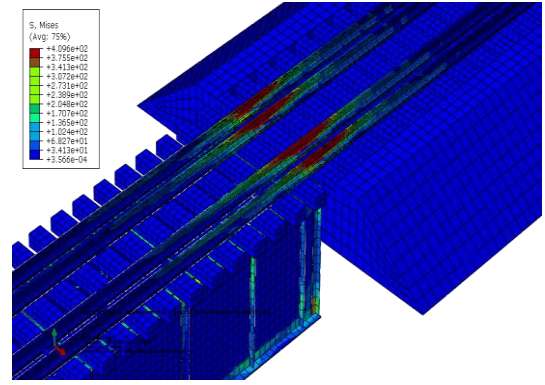


(b) Displacement of transoms and steel rail at 45°C

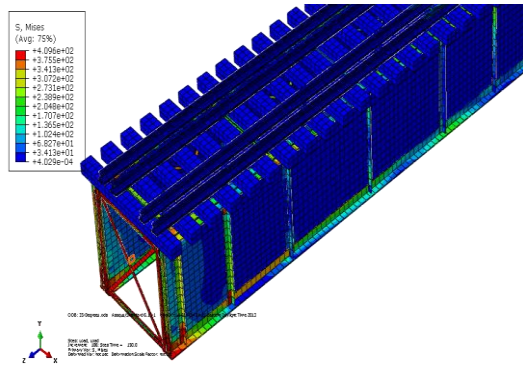
**Figure 12** Thermal loads response of Bridge-Track Systems at 40°C and 45°C



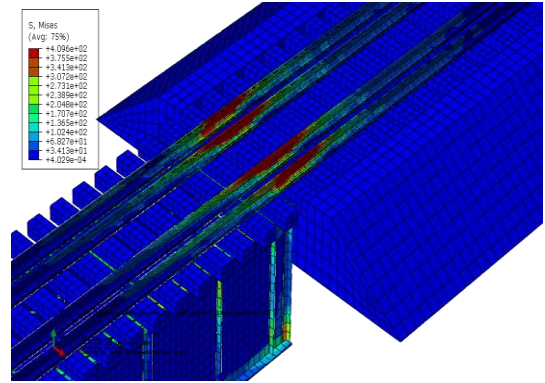
a) Stress Distribution at Front at 50°C



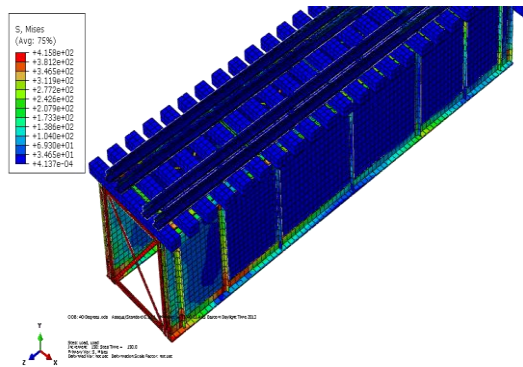
b) Stress Distribution at Back 50°C



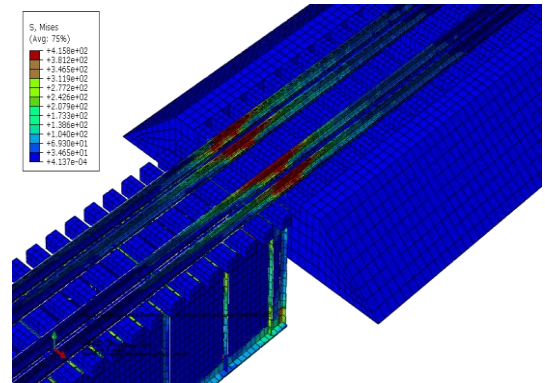
c) Stress Distribution at Front at 55°C



d) Stress Distribution at Back 55°C



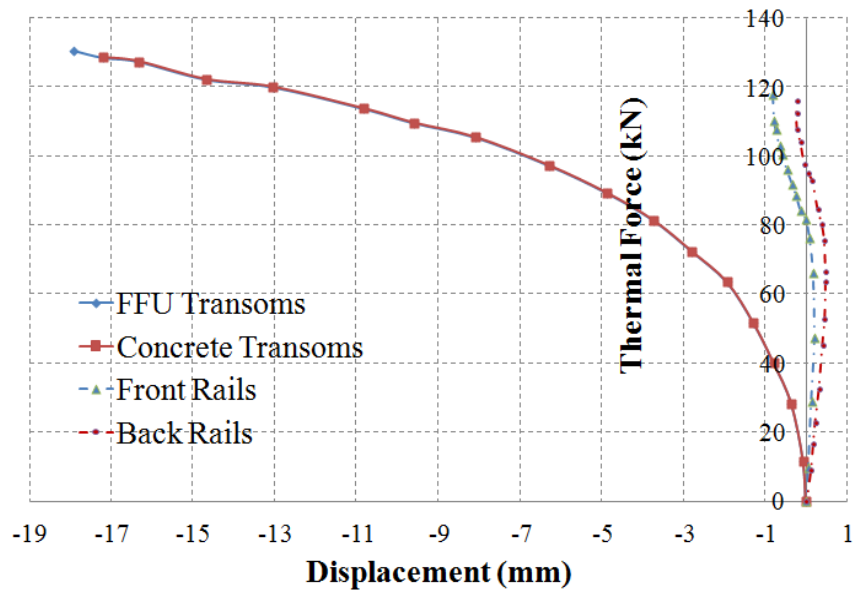
e) Stress Distribution at Front at 60°C



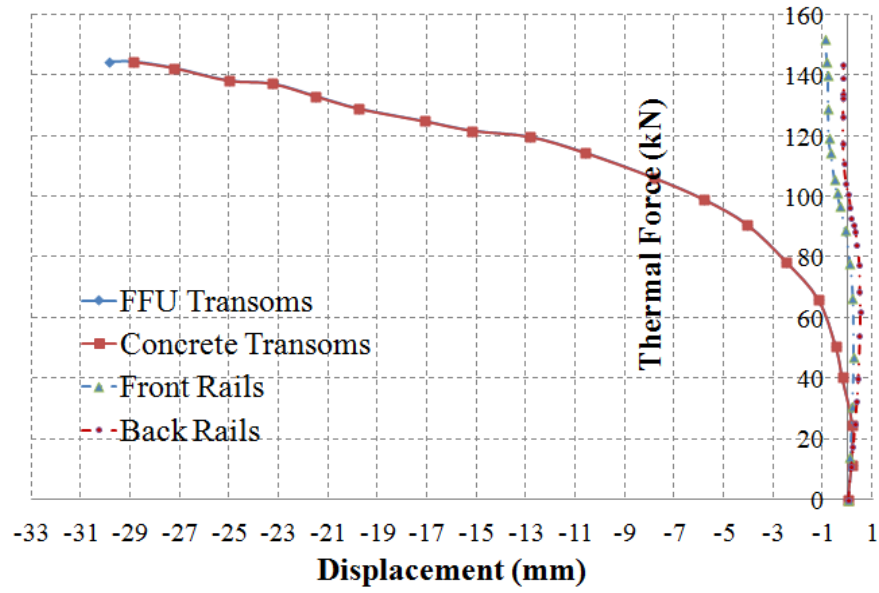
f) Stress Distribution at Back 60°C

**Figure 13** Stress Distribution at 50°C, 55°C and 60°C

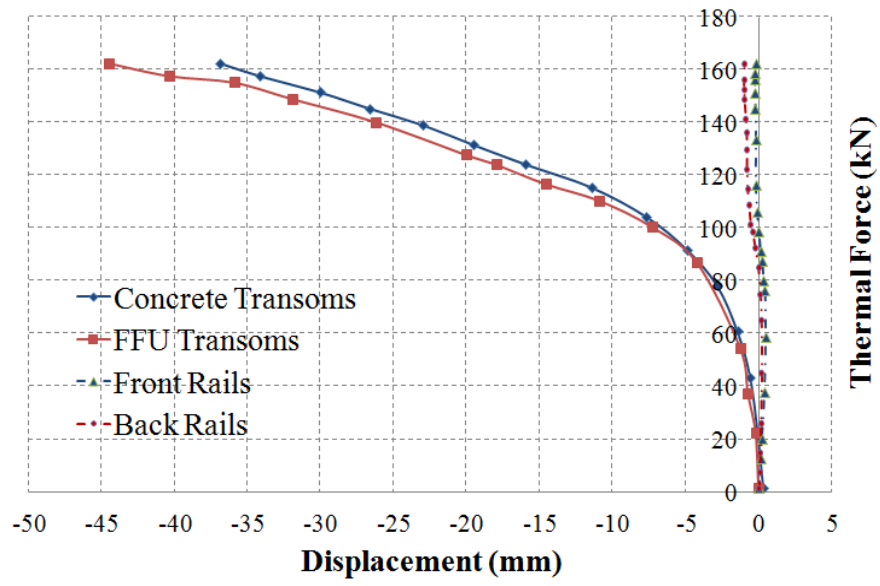




(a) Displacement of transoms and steel rail at 50°C



(b) Displacement of transoms and steel rail at 55°C



(c) Displacement of transoms and steel rail at 60°C

**Figure 14** Thermal loads response of Bridge-Track Systems at 50°C, 55°C and 60°C

# Numerical investigation into thermal load responses of railway transom bridge

Olivia Mirza<sup>5</sup>, Sakdirat Kaewunruen<sup>6</sup>, Cong Dinh<sup>7</sup>, and Edin Pervanic<sup>8</sup>

## Highlights:

- Thermal load responses of railway transom bridge are firstly investigated.
- Three dimensional finite element model has been established using material nonlinearities.
- Field data has been used to validate the model results.
- Nonlinear behavior of the bridge components is pronounced at highly elevated temperatures.
- The understanding into thermal behaviour will help track engineers to better manage rail stresses, preventing rail buckling.

---

<sup>5</sup> Senior Lecturer, School of Computing, Engineering & Mathematics, University of Western Sydney, Kingswood, NSW Australia. E-mail: o.mirza@uws.edu.au

<sup>6</sup> Corresponding Author. Senior Lecturer in Railway and Civil Engineering, School of Civil Engineering, University of Birmingham, B15 2TT, UK. E-mail: sakdirat@hotmail.com; s.kaewunruen@bham.ac.uk

<sup>7</sup> School of Computing, Engineering & Mathematics, University of Western Sydney, Kingswood, NSW Australia. E-mail: Cong.Dinh@manly.nsw.gov.au

<sup>8</sup> School of Computing, Engineering & Mathematics, University of Western Sydney, Kingswood, NSW Australia. E-mail: 16545117@student.uws.edu.au